



Sittakul, V., & Cryan, MJ. (2007). A 2.4-GHz Wireless-over-Fibre system using Photonic Active Integrated Antennas (PhAIAs) in adhoc and infrastructure modes. In *Asia-Pacific Microwave Conference, Bangkok* (pp. 1 - 4). Institute of Electrical and Electronics Engineers (IEEE). <https://doi.org/10.1109/APMC.2007.4554971>

Peer reviewed version

Link to published version (if available):
[10.1109/APMC.2007.4554971](https://doi.org/10.1109/APMC.2007.4554971)

[Link to publication record in Explore Bristol Research](#)
PDF-document

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

A 2.4-GHz Wireless-over-Fibre System Using Photonic Active Integrated Antennas (PhAIAs) in Adhoc and Infrastructure Modes

V.Sittakul and M.J.Cryan

*Centre for Communications Research, Department of Electrical and Electronic Engineering,
University of Bristol, Bristol, BS8 1UB, UK. email : vitawat.sittakul@bristol.ac.uk, m.cryan@bristol.ac.uk*

Abstract-This paper describes a low-cost scheme for implementing in-building distributed antenna systems using the Photonic Active Integrated Antenna concept whereby photonic devices are integrated directly with planar antennas. Deembedded input impedance is measured for a 850nm Vertical Cavity Surface Emitting Laser and a photodiode from 0-10GHz and the devices are matched directly to the non-radiating edge of a rectangular microstrip patch antenna. The fully bi-directional system is then tested over a 300m laboratory based MultiMode Fibre link and a 220m in-building dark-fibre link. Results are shown in adhoc and infrastructure modes for Throughput, Signal strength and Signal-to-Noise ratio. The paper shows that such systems can achieve up to 10m RF range, at reduced Throughput, with no RF amplification.

I. INTRODUCTION

The PhAIA concept is the intimate integration of photonic devices with antennas [1], it is an extension to the well known Active Integrated Antenna (AIA) concept from the microwave engineering field [2]. The fact that the photonic device and antenna are highly integrated means that very efficient impedance matching can be achieved which can lead to improved link gain [3]. It could also lead to much reduced packaging and fabrication costs. These ideas can be extended to full monolithic integration and some work as been done on photodiode-antenna integration [4].

There is much current interest in low cost Wireless-over-Fibre (WoF) systems [5-7] for distribution of mobile phone and WiFi signals within buildings. In applications such as this cost will be critical and the improved link gain and reduced packaging costs that can be achieved with PhAIAs could play an important role.

This paper presents results for a full-duplex WoF system using Vertical Cavity Surface Emitting Lasers (VCSELs) and photodiodes (PDs) integrated with microstrip patch antennas. A schematic of the link is shown in figure 1. Here a USB wireless adapter operating in 802.11b mode is used as an access point, this is connected, via a coax splitter to a VCSEL transmitter and a PD receiver. Two types of fibre link are then assessed, firstly a laboratory based 300m MultiMode Fibre (MMF) link and secondly a 220m in-building dark fibre MMF link. In both cases the fibres are connected to a VCSEL-Antenna and a PD-Antenna

and a wireless enabled laptop is then placed a distance from the PhAIAs. This configuration could form the basis for a range-extension system, discussed in detail in section V, which would tap RF power from an existing access point and feed this into an in-building fibre network and retransmit the access point signal from the low cost PhAIA-based remote node. It should be noted here that no RF amplification is being used – this will be important for maintaining low cost operation and is especially important at the remote node. It may even be possible to power the remote node using Power-over-Fibre techniques and the low operating current of the return VCSEL will be ideally suited to this application.

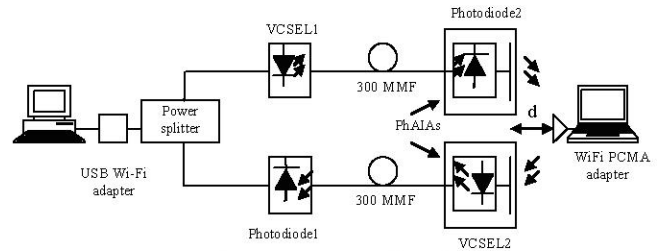


Figure 1. System configuration

In section II the performance of individual components of the link are measured. Section III assesses the PhAIAs configuration and section IV assesses the complete link in terms of Throughput and Signal-to-Noise Ratio in adhoc mode. In section V results are shown for a system in infrastructure mode and finally section VI gives conclusions and future direction for this work.

II. INDIVIDUAL COMPONENT PERFORMANCE

A. VCSELs

The link is comprised of two low cost 850nm VCSELs from Truelight (www.truelight.com.tw). In order to study the trade-offs between threshold current, slope efficiency and output power, different VCSELs are currently being used within the link. At the access point end a standard VCSEL (VCSEL1 : TSD-8B12-000) with medium slope efficiency is being used, whereas the remote end employs a high slope efficiency device (VCSEL2 : TSD-8B12-017). Lower threshold current devices are also under investigation and will be the subject of future work. Figure 2 shows L-I curves for VCSEL1 and VCSEL2, these are measured by coupling power directly in to a cleaved MMF. It can be seen that VCSEL 2 gives superior performance

with a slope efficiency of 0.44 W/A compared to 0.2 W/A for VCSEL1.

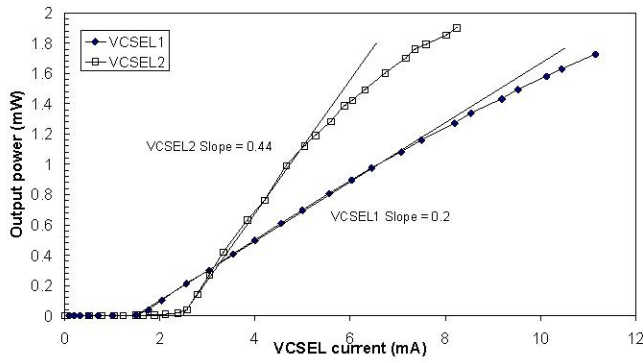


Figure 2. L-I curves for VCSEL1 and VCSEL2

B. Photodiodes

Two low cost 850nm PDs are used in the link, in this case only one type of device is used: a GaAs PIN from Truelight (TPD-8D12-006). The most important parameter of photodiode is its responsivity. To measure the responsivity of the PDs, the incident optical power generated from VCSEL1 with bias current varying from 0 to 10 mA was fed into the PD via a 1m length MMF with a flat cleaved facet. The photodiode current was plotted as a function of incident optical power. The results for PD1 and PD2 are shown in figure 3. The slope of the graph shows the responsivity of PD1 to be 0.6 A/W and PD2 to be 0.37 A/W. This highlights the amount of device-to-device spread in performance that must be anticipated within systems such as this.

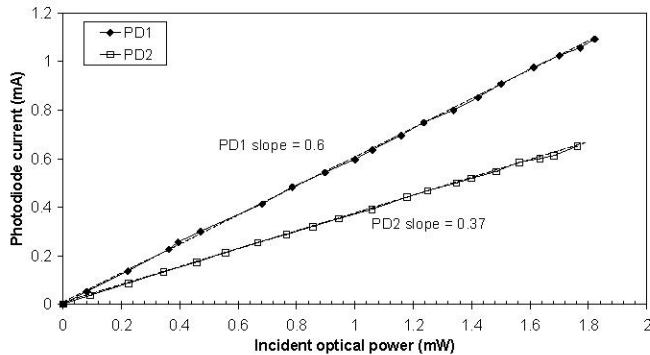


Figure 3. Photocurrent vs incident optical power for PD1 and PD2

III. PHOTONIC ACTIVE INTEGRATED ANTENNAS

Having assessed the individual components, the PhAIAs can now be studied in detail. Figure 4 shows a front view of the planar microstrip antenna being used.

The antenna is a standard rectangular microstrip patch designed to operate at 2.4GHz. A transmission line biasing circuit is also used so that VCSEL bias or PD current can flow across the patch – further reducing component count. A microstrip carrier is used to mount the photonic device and is soldered on to the reverse

side of the antenna creating a uniform ground plane for both antenna and microstrip carrier.

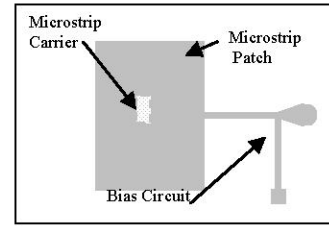


Figure 4. Front view of PhAIA showing layout of microstrip patch, bias network and photonic device carrier mounted on the reverse side.

Figure 5 (a) and (b) show side views of the VCSEL and PD integrated antenna devices. It can be seen that current can flow across the antenna, through the bond wire onto the microstrip carrier, through the VCSEL and back to the common ground through a second bond wire and ground via.

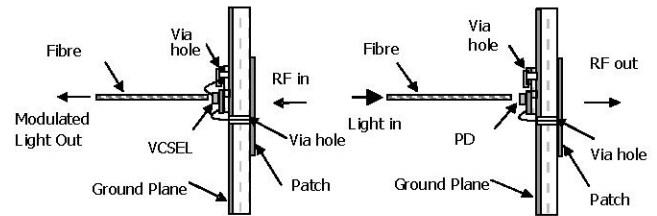


Figure 5. The configuration of PhAIAs; (a) VCSEL 2, (b) Photodiode 2

The VCSEL and PD are connected close to the centre of the non-radiating edge of the antenna this will be close to the 10-40Ω required for matching the real parts of the impedances. Work is now under way to optimise the matching for both VCSELs and PDs.

IV. EXPERIMENTAL SETUP FOR BI-DIRECTIONAL LINK USING PhAIAs IN ADHOC MODE

One of the difficulties of working with both photonic and antenna devices is that optical tables are normally required for the photonic devices and these large metal objects can severely effect radiations patterns and antenna performance. Thus a low-cost mount has been developed as shown in figure6 which allows accurate alignment of the MMF to the optical device, but does not require x-y-z stages to be used. This will enable these devices to be characterized within anechoic chambers as is required for any WiFi device.

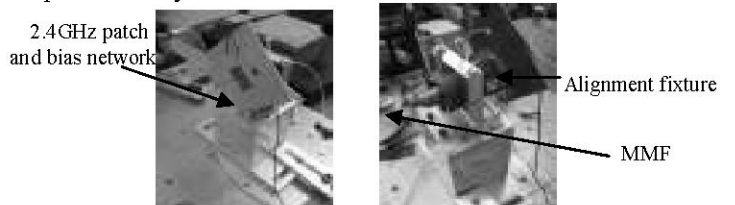


Figure 6. Portable PhAIA with photodiode (left) Front view, (right) Back view

All the components discussed in preceding sections are now brought together in a fully bidirectional twin fibre based system. The layout for the system is shown in figure 7. A USB wireless adapter was used to mimic a Hot-Spot, the external antenna was removed so that the signal could be fed directly into a non-antenna VSCSEL and PD transceiver. This system then takes this WiFi signal and can retransmit it using a remote PhAIA based transceiver after some length of MMF.

There are three main developments with respect to the configuration shown in [1]. Firstly this is fully low cost using two 850nm VCSELs and two photodiodes. Secondly there is no RF amplification used here – an important point for any low cost, low DC power system. Finally only one antenna-antenna link is used, this has the effect of increasing the input power to the link and this is main reason why amplification can be removed and the RF range has increased so dramatically from 10cm in [1] to around 10m here. It is felt this is a commercially viable configuration where RF power can be tapped off coaxially from an existing access point and fed into a purely coaxial transceiver.

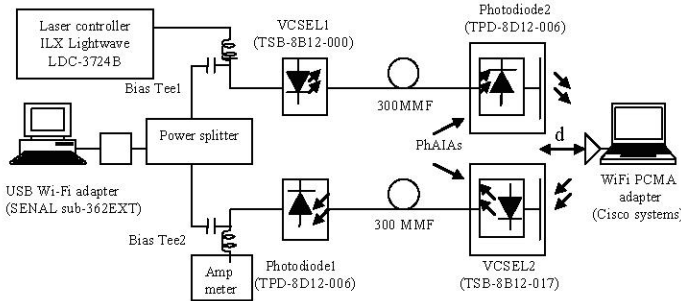


Figure 7. Diagram of bi-directional links on Adhoc mode.

At the laptop side, the distance between the PhAIA and the wireless PCMCIA adapter, d was varied from 0.1 to 10 m and the results for throughput and SNR are shown in figures 8 and 9. The Aironet client utility provided with the Cisco Wireless PCMCIA adapter was used to measure the signal to noise ratio (SNR) and proprietary software provided by Provision Communications (www.provision-comm.com) a spin-out from the University of Bristol was used to measure the throughput of the link. It was found that a WiFi link could be maintained up to a distance of 10m and results are presented at different VCSEL1 bias currents. Figure 8 shows that the throughput can be higher than 1MB/s in the range up to 2 m. It can be seen that the throughput cannot be measured for VCSEL bias currents of 4 and 6mA beyond a distance of 5.5 and 6.5 m respectively. However, by increasing the VCSEL bias current to 8 mA it can be seen that throughput measurements can be extended to 10m. If the bias current is further increased the achievable range is reduced, this is most likely due to signal distortion being induced by the non-linearities of the link. Figure 9 shows that reasonable SNR can be maintained to 10m. The set up was then used to stream video across the link and high quality video transmission was achieved to a range of 10m.

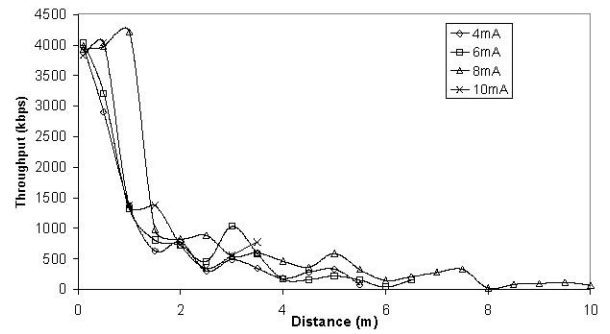


Figure 8. Throughput vs Distance at different VCSEL 1 bias current

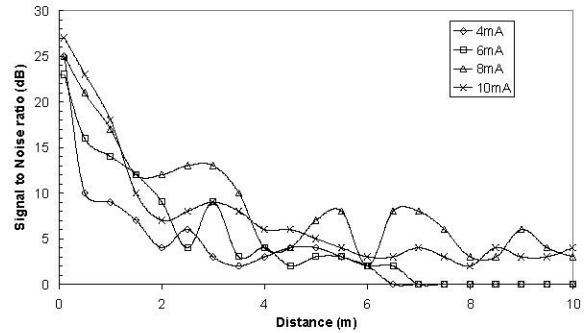


Figure 9. Signal to Noise ratio vs Distance at different VCSEL 1 bias current

These results show that a VCSEL 1 bias current of 8mA appears to give the best link performance, this value makes a balance between link gain, linearity and noise performance. It should be noted that no optimisation of VCSEL 2 bias has been performed and that reverse bias can easily be applied to the PDs to further improve this performance. The periodic nature of the results with respect to distance are most likely due to multi-path fading effects due the lab based environment in which these results were taken. The portable fixtures shown in figure 6 will now enable trials to take place within departmental anechoic chamber facilities.

As a further test for the system, trials using in-building dark fibre have taken place over link lengths of 220m. Results for throughput are shown in figure 10.

Reduced RF range performance was obtained here due to the fact that the RF loss of the in-building link was greater than the 300m link, even though it was shorter. This is believed to be due to bending losses within the in-building link.

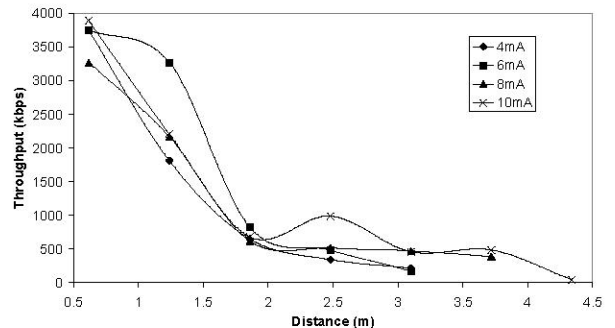


Figure 10. Throughput vs Distance at different VCSEL1 bias current

V. EXPERIMENTAL SETUP FOR BI-DIRECTIONAL LINK USING PhAIAs IN INFRASTRUCTURE MODE

The previous sections have studied the adhoc or peer-to-peer mode where only two computers communicate directly. In general, the computers will talk to each other via a router or access point in infrastructure mode. There are a number of issues associated with this in particular the long delay that the MMF will introduce into the system, thus it is important to investigate this case directly. To confirm our system can support infrastructure mode, a Router (Linksys 2.4GHz 802.11g; WRT54GL) was introduced into the system together with another desktop computer as shown in Figure 11. A video stream taken from the hard disk of desktop1 was successfully played on the Laptop screen while desktop computers were used to access the router at the same time. Then the software provided by Provision Communications was used to measure the throughput and the signal strength of the link between the laptop and the desktop1. Laptop1 was moved away from the patch antennas with distance (d) and the throughput, signal strength were measured as shown in figures 12 and 13.

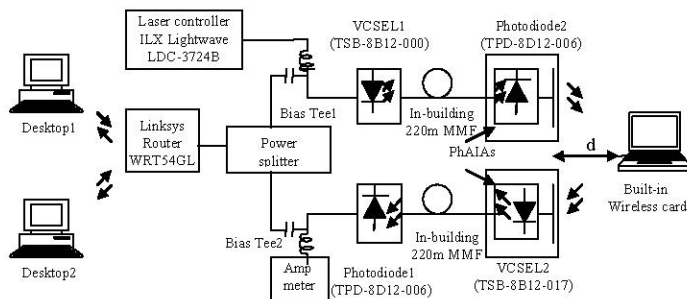


Figure 11. Diagram of bi-directional links on Infrastructure mode.

The measured throughput and signal strength in infrastructure mode are very close to that in adhoc mode. Further investigation is required to completely understand the role of large delays and losses in systems such as this.

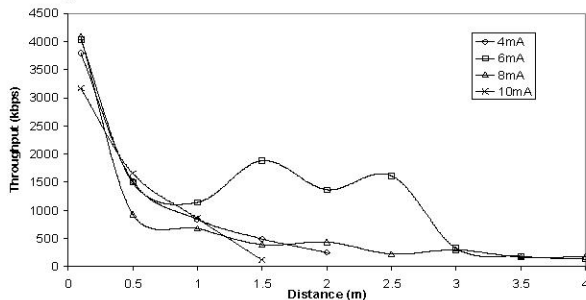


Figure 12. Throughput vs Distance at different VCSEL1 bias current

VI. CONCLUSION

This paper has presented a detailed study of wireless-over-fibre links in adhoc and infrastructure modes based on the PhAIA concept where photonic devices are integrated directly with planar antennas. This approach will enable very efficient conjugate matching between the photonic device and the antenna

to be achieved which will in turn result in improved link gain. The systems described have yet to be optimised in terms of impedance matching, bias currents and antenna resonant frequency and bandwidth, thus much improved performance is expected for future system iterations. The system is inherently very low cost and does not use any RF amplification, though the additions of low noise amplifiers would be a straightforward extension. This would however require substantial DC power at the remote node and it is felt this will severely impact the commercial viability of the approach. It is possible to deliver DC electrical power using Power-over-Fibre techniques and these are currently being pursued in conjunction with the Electrical Energy Management research group at the University of Bristol. Systems are also being developed in the millimetre wave bands where antenna sizes become very much reduced and the possibility of fully monolithic wireless-over-fibre transceivers with integrated antennas remain an interesting possibility.

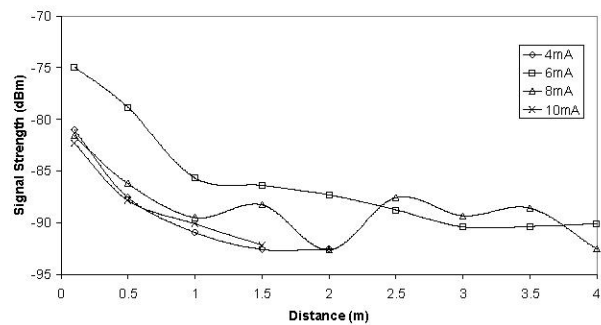


Figure 13. Signal strength vs Distance at different VCSEL1 bias current

ACKNOWLEDGEMENT

The authors would like to thank Thai government for funding of this PhD study and Prof. Dave Bull of Provision Communications and Pierre Ferre for providing the throughput measurement codes.

REFERENCES

- [1] M.J.Cryan, M.Dragas, J.Kung, V.Jain, F.Fornetti, T.Houle, R.Varrazza, M.Hill, "A 2.4GHz Wireless-Over-Fibre Transceiver using Photonic Active Integrated Antennas (PhAIAs)", *Microw Opt Tech Lett*, Feb 2006.
- [2] M.J.Cryan, P.S.Hall, K.S.H.Tsang and J.Sha "Integrated active antenna with full duplex operation", *IEEE Trans. Microwave Theory and Tech*, Vol.45, No.10 October 1997.
- [3] Charles H.Cox III, *Analog Optical Links Theory and Practice*, Cambridge University press, 2002.
- [4] Ito *et al*, "Photonic millimetre-wave emission at 300 GHz using an antenna-integrated uni-travelling-carrier photodiode", *Electronics Letters*, Vol. 38 No. 17, August 2002
- [5] A. Das *et al*, "Design of Low-cost MMF-Fed Indoor Wireless Networks", *IEEE Trans. on Microwave Theory and Tech*, Vol.54, No.8, Aug 2006.
- [6] A. Nkansah *et al*, "Simultaneous Dual Band Transmission Over Multimode Fiber-Fed Indoor Wireless Network", *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 11, November 2006
- [7] C.P. Liu *et al*, "Design, Fabrication And Characterisation Of Normal-Incidence 1.56um Multiple-Quantum-Well Asymmetric Fabry-Perot Modulators For Passive Picocells", *IEICE Trans. Electron.*, Vol.E85-C, No.1 January 2002